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MEMORANDUM REPORT ARBRL-MR-02946

CARBON FIBER TRANSFER FUNCTIONS THROUGH FILTERS AND ENCLOSURES

John J. Paszek
Dudley D. Davis
James H. Patrick

March 1980

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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Experimentally determined values for the transfer of carbon fibers through air filters and electrical equipment cabinets are given together with a description of an improved technique for measuring carbon fiber exposure. The data show that even coarse filters greatly reduce the transfer of carbon fibers.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Con't)

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION

Carbon fibers are electrically conducting. When electrical equipment is operated in a carbon fiber laden environment, fibers may enter the equipment, bridge electrical gaps and cause malfunctions. The number of fibers entering the equipment is a direct function of the environmental exposure and any medium which intervenes the equipment and its environment. An example of such a medium is an air filter. This report gives experimentally determined transfer functions for air filters, air conditioning duct work, and equipment cabinets.

II. FILTER TESTS

A. Test Facilities and Procedures

1. Test Facilities.

a. Test Chamber. The filter transmission tests were performed inside the S-280 electrical equipment shelter (ECOM chamber) which is an air tight enclosure fitted with a tight sealing door. The walls, ceiling, and floor are all smooth surfaces, which facilitate cleaning between tests. Interior dimensions are 3.5 m long, 2.1 m wide, and 1.9 m high. Inside the chamber, 12 muffin fans, placed in as many locations, act to keep introduced fibers suspended in the chamber air.

b. Fiber Disseminator. The BRL Fiber Disseminator[1] was used to fill the chamber with a cloud of single fibers. The disseminator is a tubular vertical column 15 cm in diameter and 1 m high; it is powered by compressed air. Two independent air streams separate the fibers, disperse them throughout the air in the column, and finally inject them into the test chamber. One air stream is continuous and provides a gentle current of air up the column and out of the top through a small opening. The other air stream is intermittent; periodic short blasts of air lift small clumps of fibers from the fiber reservoir at the bottom upward into the column where they are gently agitated and separated. Single fibers continue rising with the upward air current until they are ejected at the top; remaining small clumps of fibers drift downward back into the reservoir. The intermittent air blast is provided by an electrical solenoid valve controlled by a timer, and both the duration of the blast and the interval between blasts are adjustable. With the disseminator, the concentration of fibers in the chamber can be controlled over a large range (5×10^3 - 2×10^5 f/m^3) and held constant for a long period of time ($\sim$ 30 min).

c. Filter Test Fixture. The specimen filter was mounted in a tubular test fixture that provided a controllable air flow through the filter. The fixture is 15 cm in diameter and 2 m long (see Figure 1) and consists

[1] *Neil Wolfe, private communication, "The BRL Fiber Disseminator".*

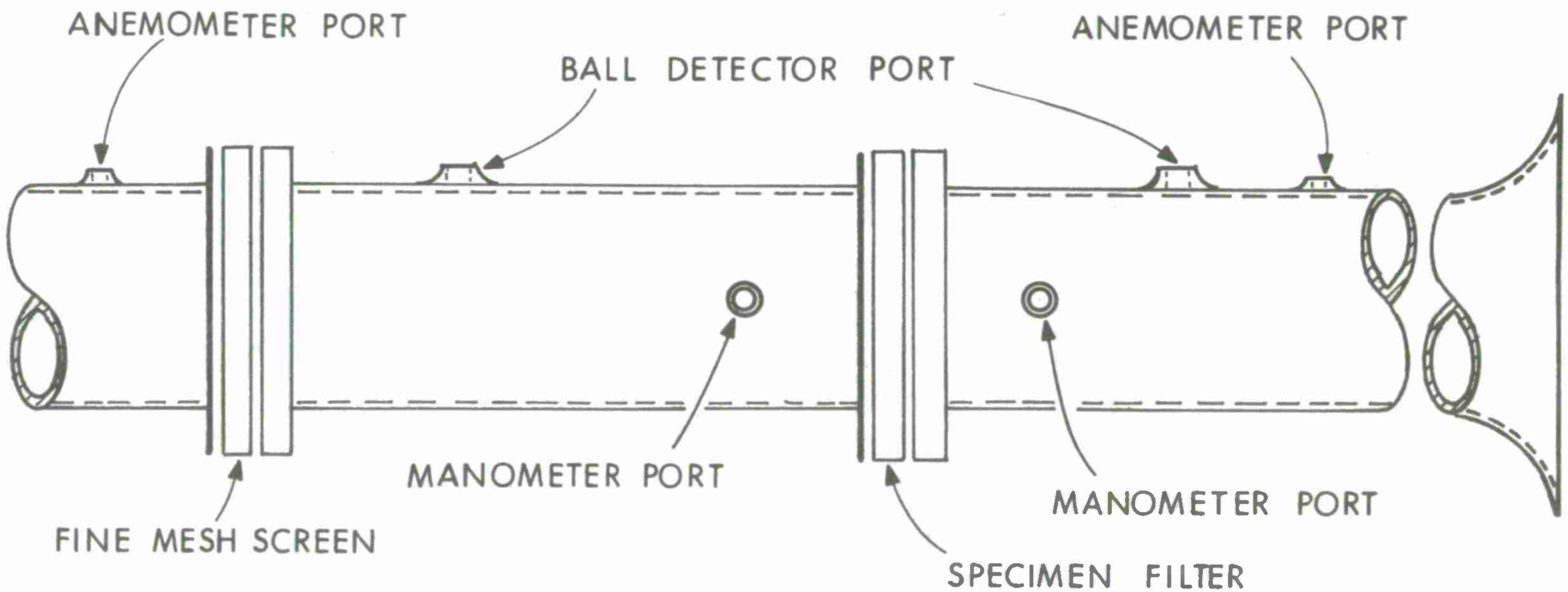

Figure 1. Filter Test Fixture

of three sections fitted with flanges that allow the sections to be bolted together. The filter was mounted between two of the sections in a manner that allowed no air flow around the edges of the filter. A fine mesh screen (111 μm opening) was similarly mounted downstream of the filter to collect fibers that passed through the filter. A variable speed blower attached to the downstream end draws air through the assembly. Two charge transfer detectors are symmetrically mounted, one upstream of the filter and one downstream. A hot wire anemometer monitors the air flow through the filter and a manometer measures the pressure drop across it.

The test fixture blower assembly is operated completely inside the test chamber; it ingests chamber air and exhausts back into the chamber.

2. Measurements. The filters were tested with 3 lengths of fiber and for 3 rates of air flow. Concentration and exposure were determined with the charge transfer ball detector, and fiber length distribution was determined using sticky tape and the fine mesh screen. The following determinations were made:

a. Concentration and Exposure as a Function of Time. Fiber concentration was determined with the charge transfer ball detector. The system consists of the ball, a multi-channel analyzer, and a voltage level discriminator. The electrically charged ball gives up a portion of its charge to fibers that pass within a certain distance of it. The electrical pulses produced by this transfer of charge represent counted fibers and, with proper calibration, fiber concentration.[2]

The multi-channel analyzer is an array of 1024 storage registers in which the fiber counts are stored. The array is divided into two groups, one for each ball, and the counts from the upstream ball and the downstream ball are recorded simultaneously. Each pair of channels sums and stores counts for a fixed interval of time, typically 1 to 5 seconds. The channels are addressed sequentially and incremented with time so that the full array records for the duration of the test. Concentration and exposure as a function of time are derived from this recording.

The ball is connected to the multi-channel analyzer through a voltage level discriminator. The discriminator prevents low level electrical noise pulses from being counted as fibers. It also determines the shortest length fiber that the system will count, since the amplitude of the electrical pulse from the ball is a function of the length of the fiber. Care is taken to shield against noise so that the discriminator may be set low enough to count the shortest fibers expected to be encountered. The discriminator setting is given as an equivalent fiber length for each test.

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[2] *John A. Morrissey, William Brannan, and Samuel Thompson, "Calibration of BRL Ball and Sticky Cylinder Detector Systems (U)," Ballistic Research Laboratory, Technical Report ARBRL-TR-02079, Jun 78, (UNCLASSIFIED).* (AD #B029204L)

The charge transfer balls are mounted, symmetrically, upstream and downstream of the filter (see Figure 1) and filter performance is determined from the ratio of the two ball measurements. Note that the ball positions are physically and electrically similar and that the counts from the two balls are recorded simultaneously. This assures the same response from both balls and acts to cancel the effects of calibration errors and of variations occurring during the test such as, for example, a change in the air flow rate. The ratio of the two ball measurements possesses greater accuracy than is found in either ball measurement taken separately.

b. Filter Transmission Factor as a Function of Exposure. The filter transmission factor, the ratio of the downstream exposure to the upstream exposure, was derived from the recorded charge transfer ball data. The transmission factor is a measure of the effectiveness of the filter.

c. Fiber Length Distribution. The fiber length distribution was sampled upstream and downstream of the filter. The upstream sampling was done by collecting fibers on sticky tapes at several locations in the test chamber; the downstream sampling by collecting fibers on the fine mesh screen in the test fixture. The fine mesh screen collects virtually 100% of the fibers that pass through the specimen filter. It is made from polyethylene filaments and has a mesh opening of 111 μm
After the test run, sticky tapes were used to remove the fibers from the fine mesh screen. The tapes, which are 39 mm squares and transparent, were mounted in 35 mm slide holders and projected, magnified 10 times, onto a screen where the fibers were counted for number and measured for length. The amount of fiber breakup through the filter was determined from a comparison of the fiber length distribution upstream and downstream of the filter.

d. Air Flow Rate and Pressure Differential. The velocity of the air flow through the filter was monitored throughout each test with a hot wire anemometer. A manometer monitored the increase in the pressure drop across the filter from the beginning of the test to the end (ΔP).

3. Test and Cleanup Procedures. The fiber disseminator and the 12 muffin fans were operated to produce and maintain a relatively high concentration of carbon fibers in the chamber air. This fiber laden air was drawn through the specimen filter (by the blower attached to the test fixture) until the exposure became approximately 1×10^7 fiber-seconds/m^3 at the input detector (Ball #1). The duration of the test ranged from 30 to 40 minutes.

A formal cleanup followed each test run. The interior of the test chamber was vacuum cleaned. The filter test fixture was disassembled and vacuum cleaned inside and out. Following the vacuum cleaning the chamber and test fixture were wiped down with a damp sponge. The chamber and test fixture were inspected and, if necessary, the procedure was repeated.

The fine mesh screen was vacuum cleaned, air blown, inspected, and finally pressed against a large sheet of sticky tape. If the tape showed that fibers remained on the fine mesh screen, the procedure was repeated.

B. Specimen Filters - Description, Preparation, and Test Results

1. Fiberglass Furnace Filters.

a. Description. These are 2.54 cm thick adhesive coated fiberglass filters of the type commonly used in household furnaces; the manufacturer is the American Air Filter Company, Inc., Louisville, Kentucky. They bear the designation: Filters, Air Conditioning, Type I, together with the federal stock number - FSN 4130-00-542-4482.

b. Preparation. The adhesive that the manufacturer applies to these filters is principally a water soluble hydrocarbon oil that can lose effectiveness with continuing filter use. For this reason the filters were divided into three groups. The first group was tested as received; the second and third groups were tested after use, i.e., after air had been passed through the filter at a flow rate of 3.6 m/s, for 30 and 60 eight-hour days, respectively. Since the air was somewhat dust laden, these filters were moderately soiled when tested. A separate filter was used for each test.

c. Test Results. Percent fiber transmission was determined with Hercules AS fibers in three lengths - 3.5 mm, 7.5 mm, and 15 mm. For each length of fiber a test run was made at each of three rates of air flow - 0.5 m/s, 2 m/s, and 3.5 m/s.

The results of the 27 tests are summarized in Tables I, II, and III where the percent fiber transmission is presented for each of six levels of input exposure for each test run. The exposure is given in fiber-seconds/m^3; the number heading each of the six columns of fiber transmission data is the input exposure divided by 1×10^5. The tables include the discriminator setting as an equivalent fiber length and ΔP, the increase in the pressure drop across the filter from the beginning to the end of the test run.

TABLE I FILTER TRANSMISSION RESULTS

FILTER: FURNACE (FIBERGLASS, 25mm thick) - NEW

			FIBER TRANSMISSION (%) INPUT EXPOSURE X 10^{-5} fiber-s/m^3						
RUN NO.	FIBER LENGTH (mm)	AIR VEL (m/s)	1	5	10	20	50	100	DISCRIM CUTOFF (mm)	Δ P (mm of water)
1	3.5	0.5	*	0.4	0.4	0.4	0.5	1.2	2.0	0
2	3.5	2.0	*	*	0.2	0.1	0.2	0.3	2.0	0.5
3	3.5	3.5	*	1.4	1.5	1.8	3.5	2.4	2.0	2.3
4	7.5	0.5	*	*	*	*	*	0.4	2.5	0
5	7.5	2.0	*	*	*	0.2	0.1	0.1	2.5	0.8
6	7.5	3.5	2.0	0.4	1.3	2.0	3.4	3.0	2.5	6.0
7	15	0.5	*	*	*	0.1	*	*	4.0	0
8	15	2.0	1.0	0.2	0.1	0.1	*	*	4.0	1.8
9	15	3.5	*	0.6	2.0	1.9	2.1	2.6	4.0	1.8

FIBER - HERCULES TYPE AS

* LESS THAN 0.1% TRANSMISSION

TABLE II FILTER TRANSMISSION RESULTS

FILTER: FURNACE (FIBERGLASS, 25mm thick) - 30 Days

RUN NO.	FIBER LENGTH (mm)	AIR VEL (m/s)	FIBER TRANSMISSION (%) INPUT EXPOSURE X 10^{-5} fiber-s/m^3 1	5	10	20	50	100	DISCRIM CUTOFF (mm)	Δ P (mm of water)
1	3.5	0.5	*	0.4	0.8	1.6	1.3	1.2	2.0	0
2	3.5	2.0	*	2.8	2.5	2.5	4.1	2.9	2.0	0.8
3	3.5	3.5	23.0	9.8	6.6	7.1	7.3	7.0	2.0	1.8
4	7.5	0.5	*	0.2	0.1	0.2	0.4	0.3	2.5	0
5	7.5	2.0	1.4	0.2	0.1	0.3	0.7	1.0	2.5	0.3
6	7.5	3.5	*	1.3	1.1	1.0	1.1	0.8	2.5	2.0
7	15	0.5	*	*	*	*	*	*	4.0	0
8	15	2.0	*	0.8	0.4	0.2	0.3	0.3	4.0	0.8
9	15	3.5	1.1	1.9	1.9	2.0	2.0	2.0	4.0	1.8

FIBER - HERCULES TYPE AS

* LESS THAN 0.1% TRANSMISSION

TABLE III FILTER TRANSMISSION RESULTS

FILTER: FURNACE (FIBERGLASS, 25mm thick) - 60 Days

RUN NO.	FIBER LENGTH (mm)	AIR VEL (m/s)	FIBER TRANSMISSION (%) INPUT EXPOSURE X 10^{-5} fiber-s/m^3 1	5	10	20	50	100	DISCRIM CUTOFF (mm)	Δ P (mm of water)
1	3.5	0.5	*	*	*	*	*	0.4	2.0	0.3
2	3.5	2.0	1.9	3.3	2.9	2.6	2.8	2.3	2.0	0.5
3.	3.5	3.5	22.2	16.4	18.7	14.5	12.8	12.8	2.0	1.3
4	7.5	0.5	*	*	*	*	*	*	2.5	1.3
5	7.5	2.0	*	*	1.7	1.7	1.5	1.3	2.5	0
6	7.5	3.5	6.4	6.7	6.1	6.7	9.0	11.1	2.5	1.3
7	15	0.5	*	*	*	*	*	*	4.0	0
8	15	2.0	*	*	0.4	0.3	0.2	0.1	4.0	0.3
9	15	3.5	5.6	7.8	5.8	5.4	4.0	3.6	4.0	1.8

FIBER -HERCULES TYPE AS

* LESS THAN 0.1% TRANSMISSION

For the new furnace filters, tested at a flow rate of 2 m/s or less, the fiber transmission was 1.2% as a maximum and was generally less than 0.4%. At 3.5 m/s, the maximum fiber transmission was 3.5%. The furnace filters that had 30 and 60 days use before testing showed generally greater fiber transmission. The greater transmission occurred mainly at the highest (3.5 m/s) air flow rate and was significantly greater for the shortest (3.5 mm) fiber.

The results are presented graphically for a single run. Figures 2 and 3 show concentration and exposure (the smooth curve) as a function of time upstream and downstream of the filter. A representative plot of fiber length distribution upstream and downstream of the filter is presented in Figure 4. As can be seen, there was very little fiber breakup through these filters.

2. Pleated Panel Filter.

a. Description. The Taffco Pleated Panel Filter employs a thin (3 mm) but dense filter medium arranged in an accordian fold to increase the surface area. With the medium folded, the nominal thickness of the tested filters is 5 cm. Two similar filters having efficiency ratings of 40% and 60% were tested. The efficiency rating refers to the weight fraction of a standard synthetic dust stopped by the filter. The manufacturer is Tidewater Air Filter Fabrication, Inc.

b. Preparation. To ensure an airtight seal at the edges, the filter medium was removed from its frame, the pleats were removed, and circular pieces were cut to fit the test fixture. A separate filter was used for each test.

c. Test Results. These filters were tested with Hercules AS fibers of a single length, 3.5 mm, at 3 rates of air flow. The percent fiber transmission for these filters was very low. The number of fibers penetrating the filter ranged between 9 and 390 depending on the air velocity and filter medium efficiency (40% or 60%). Accordingly, the ball detector was not used to determine the downstream exposure. Instead, a visual count was made of all of the fibers collected on the fine mesh screen and from this we calculated the downstream exposure and the percent transmission. The precision of these experiments does not justify expressing the percent transmission to 3 decimal places. However, the relative ordering of these small numbers is possibly valid information. The test results are given in Table IV.

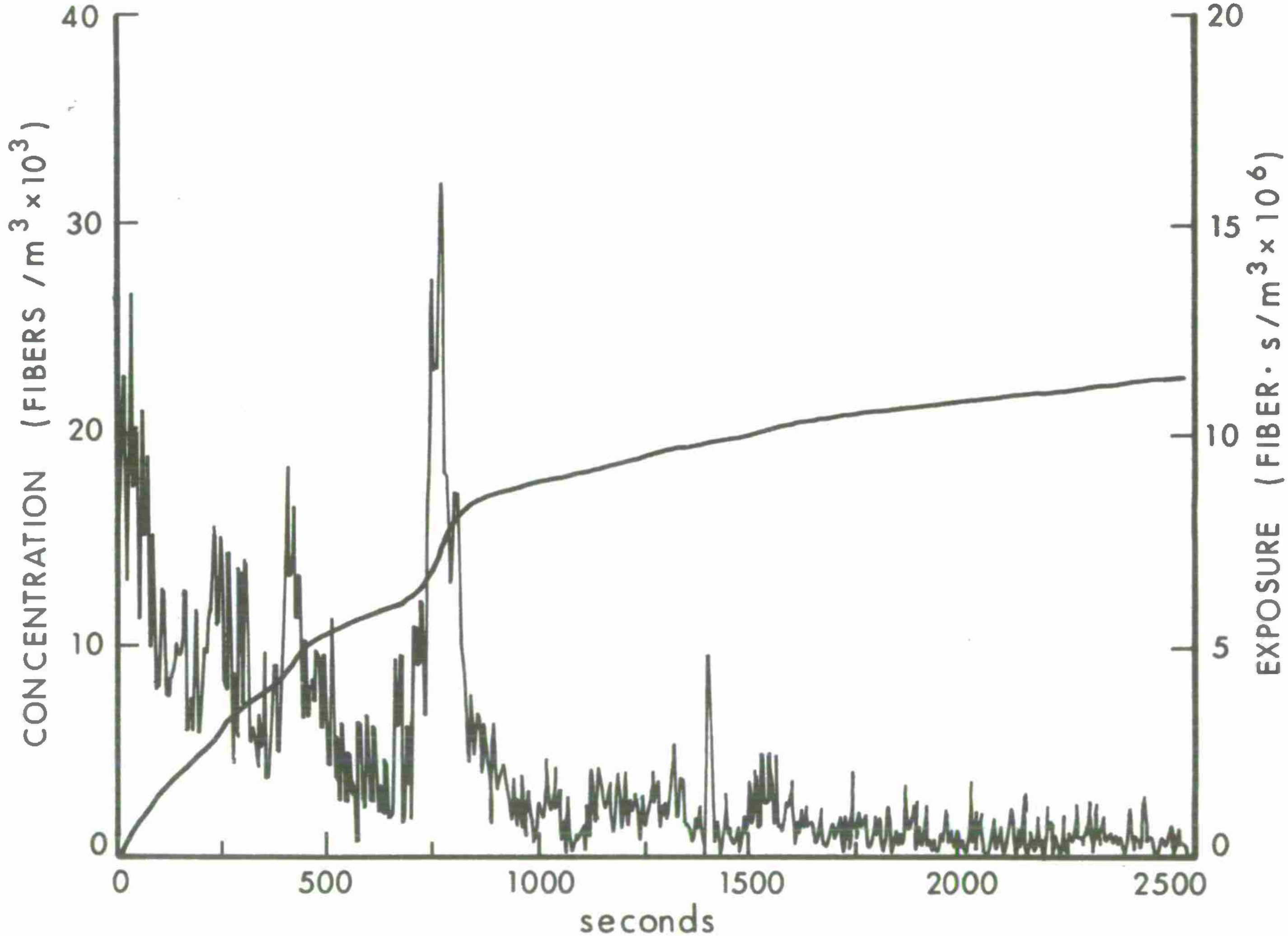

Figure 2. Typical Upstream Concentration and Exposure Plot for Furnace Filter Tests

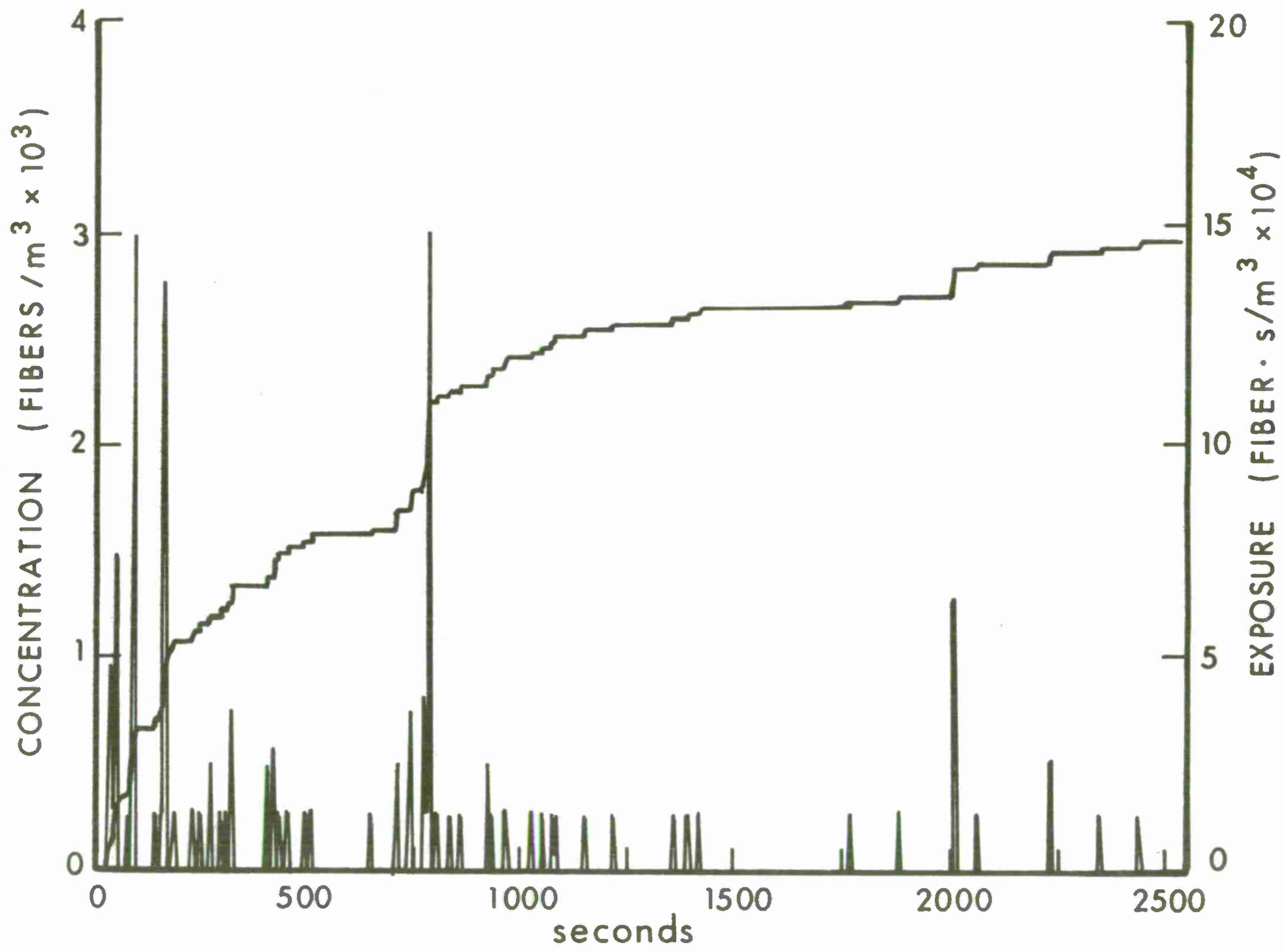

Figure 3. Typical Downstream Concentration and Exposure Plot for Furnace Filter Tests

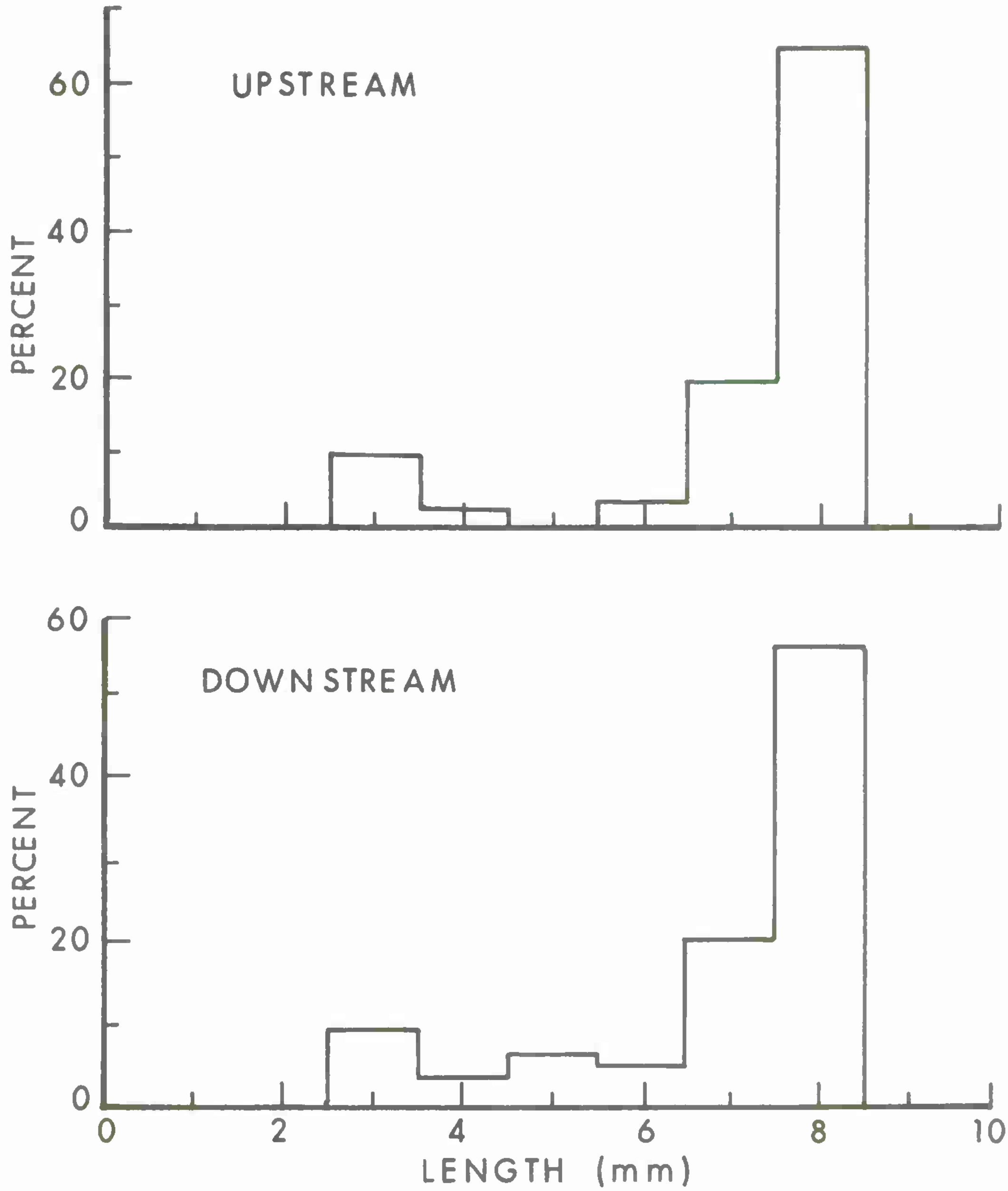

Figure 4. Typical Length Distributions for Furnace Filter Tests

TABLE IV. FILTER TRANSMISSION RESULTS

FILTER: PLEATED PANEL - 40% AND 60% EFFICIENCY

INPUT EXPOSURE - 1.3×10^7 fiber-s/m^3

RUN NO.	AIR VEL (m/s)	TOTAL DOWNSTREAM FIBER COUNT	FIBER TRANSMISSION (%)	ΔP (mm of water)
		40 PERCENT EFFICIENCY		
1	0.5	29	.024	0.3
2	1.5	120	.031	0.5
3	3.0	390	.058	1.0
		60 PERCENT EFFICIENCY		
4	0.5	9	.006	0.3
5	1.5	18	.005	0.5
6	3.0	107	.015	1.8

FIBER - HERCULES TYPE AS, 3.5 mm LONG

3. Window Screen.

a. Description. The specimen filter is copper window screen. The screen is made from 0.3 mm diameter wire and has a rectangular opening between wires of 1.2 mm by 1.6 mm.

b. Preparation. A circular piece of screen was cut for mounting in the filter test fixture. It was clamped between gaskets that allowed no air flow around the edges. Since one piece of screen was used for all the tests a thorough cleaning and a careful inspection followed each test run.

c. Test Results. Hercules AS fibers in three lengths - 3.5 mm, 7.5 mm, and 15 mm were used for the window screen tests. For each length of fiber a test run was made at each of three rates of air flow 0.5 m/s, 2.0 m/s, and 3.6 m/s.

The window screen is an effective filter for carbon fibers at an air flow rate of 0.5 m/s, but the effectiveness decreases with increasing air flow rate and decreasing fiber length. The results of the nine tests are summarized in Table V. The filter transmission factor is presented for each of six levels of exposure for each test run. The table includes the discriminator setting and ΔP, the increase in the pressure drop across the filter from the beginning to the end of the test run. The results are presented graphically for a single run in Figures 5, 6, and 7. Figures 5 and 6 show the concentration and exposure as a function of time, upstream and downstream of the filter.

There was little fiber breakup through the window screen. This is illustrated by the graphs of fiber length distribution, upstream and downstream of the window screen, presented in Figure 7.

4. Room Air Conditioner Filters.

a. Description. Two similar adhesive coated fiberglass filters, 10 mm and 12 mm thick respectively, were tested. Intended for use in room air conditioning units, this type of filter medium is supplied in 0.4 m x 15 m rolls and is typically about 12 mm thick; the medium is cut to fit the application. Although the two filters were similar and were made by the same manufacturer, the 12 mm thick medium was coarser and less uniform than the 10 mm medium. The federal stock number for the 10 mm thick medium is 4130-00-X05-0029; for the 12 mm thick medium it is 4130-00-906-2246. Both are a product of DRICO INDUSTRIAL CORPORATION.

b. Preparation. The filters were tested as received using a separate piece of the medium for each test.

c. Test Results. These filters were generally as effective as the furnace filters. However, the transmission was higher at low levels of exposure and higher for the 3.5 mm long fiber through the 12 mm

TABLE V. FILTER TRANSMISSION RESULTS

FILTER: WINDOW SCREEN

RUN NO.	FIBER LENGTH (mm)	AIR VEL (m/s)	FIBER TRANSMISSION (%) INPUT EXPOSURE X 10^{-5} fiber-s/m^3						DISCRIM CUTOFF (mm)	Δ P (mm of water)
			1	5	10	20	50	100		
1	7.5	2.0	4.0	5.8	4.8	4.8	3.8	3.6	3.5	0.6
2	7.5	0.5	2.0	1.6	1.2	1.2	1.2	1.2	3.5	0.4
3	7.5	3.6	21.0	11.4	10.1	9.6	6.8	4.3	3.5	3.2
4	3.5	2.0	57.0	42.4	36.8	31.0	25.6	16.4	2.0	0.4
5	3.5	0.5	8.0	4.4	3.3	3.4	3.0	2.7	2.0	0.3
6	3.5	3.6	44.0	49.0	39.4	31.4	20.1	15.9	2.0	3.1
7	15	3.6	16.0	9.6	10.0	8.5	6.4	4.5	4.0	2.8
8	15	0.5	2.0	0.4	0.6	0.3	0.1	0.1	4.0	0.3
9	15	2.0	2.0	1.8	2.8	3.9	4.4	3.7	4.0	0.4

FIBER - HERCULES TYPE AS

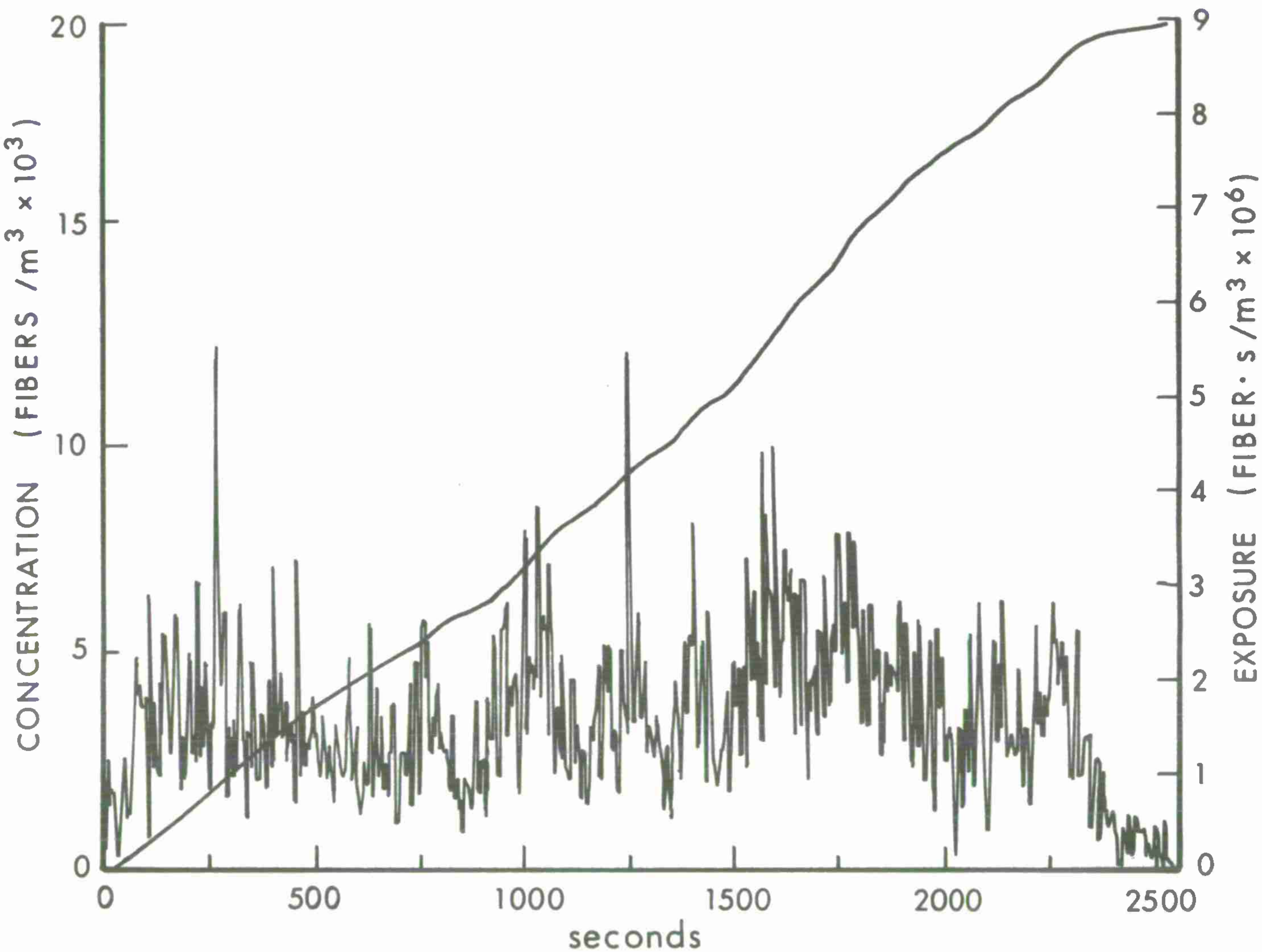

Figure 5. Typical Upstream Concentration and Exposure Plot for Window Screen Tests

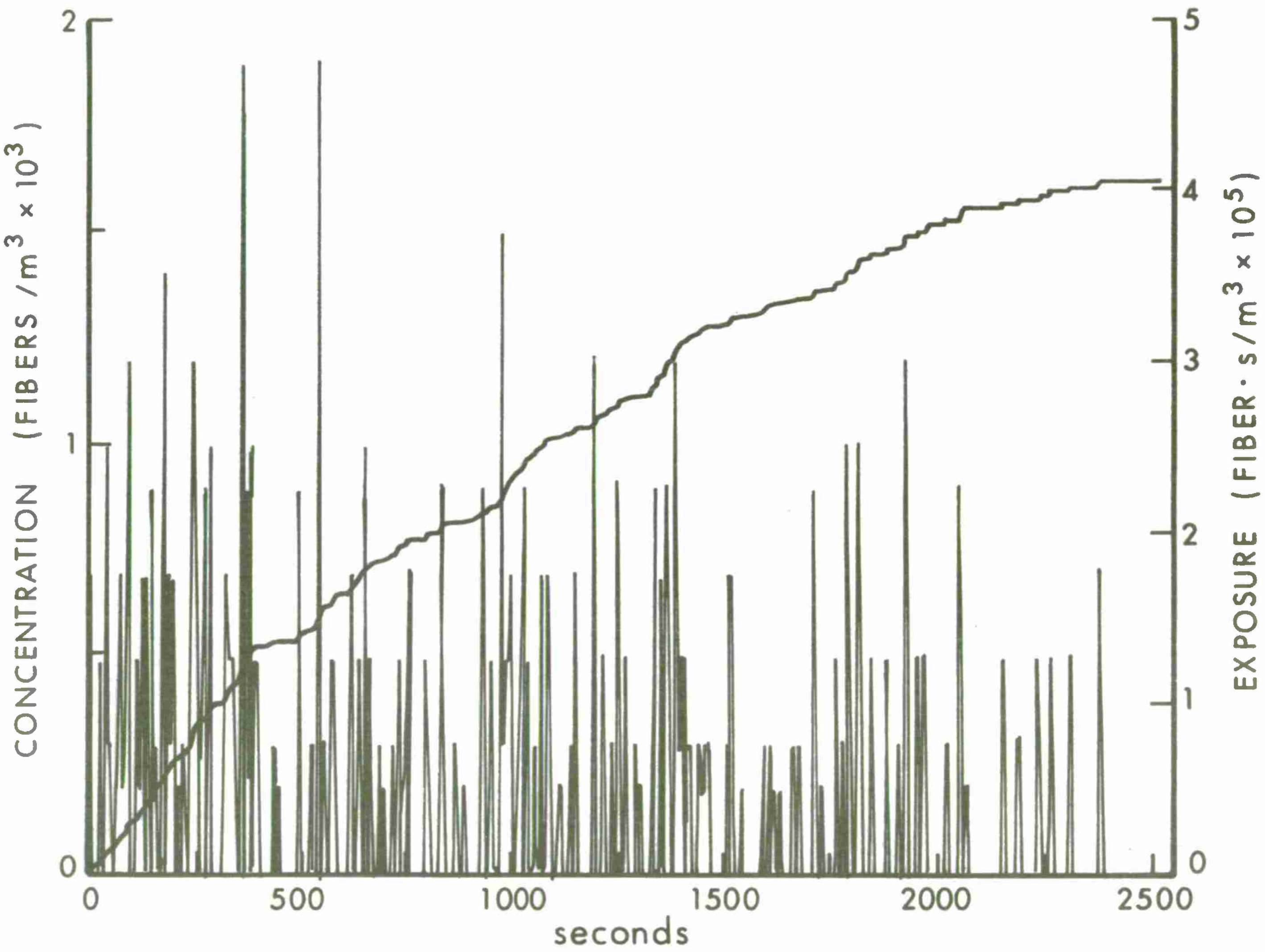

Figure 6. Typical Downstream Concentration and Exposure Plot for Window Screen Tests

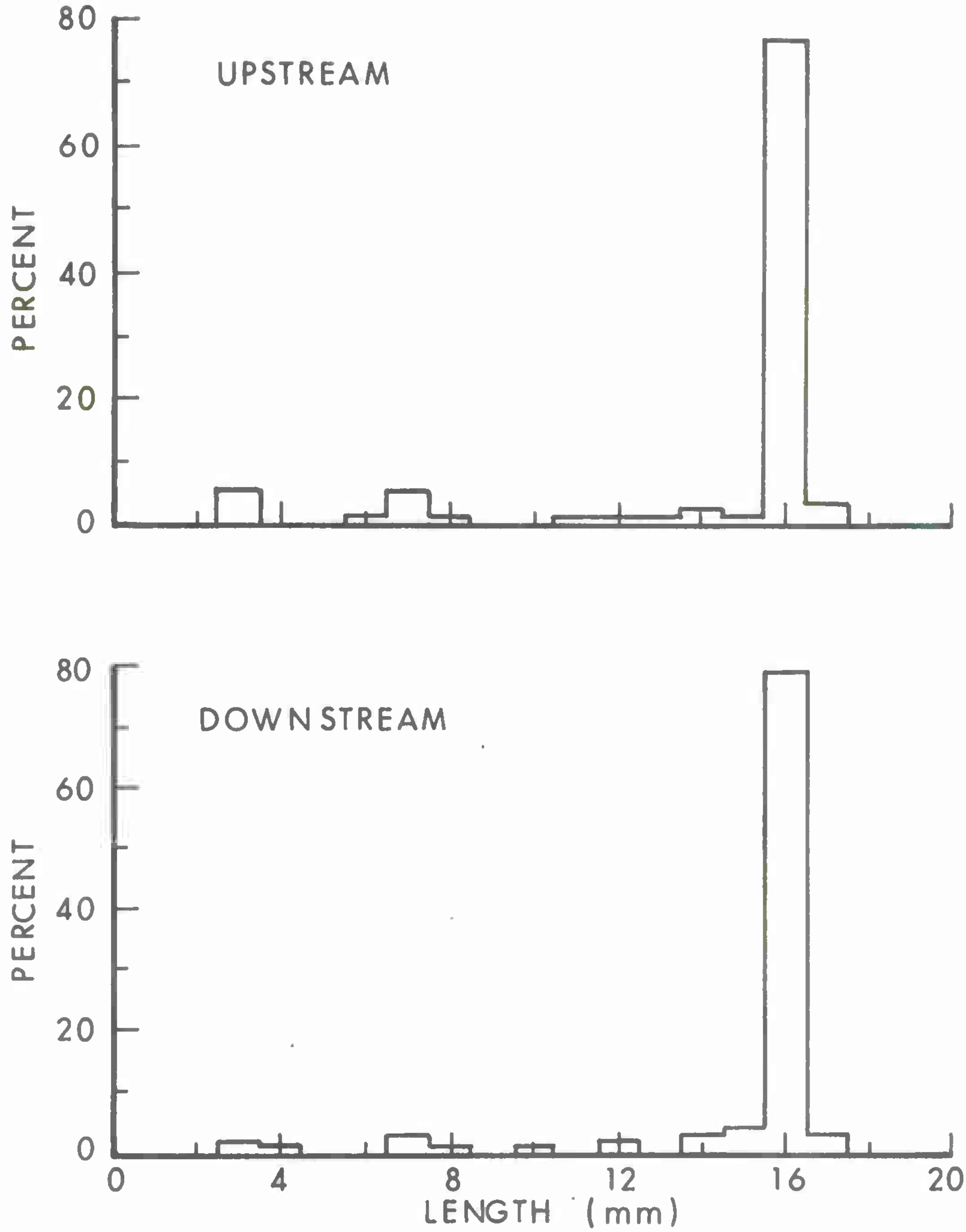

Figure 7. Typical Length Distributions for Window Screen Tests

thick filter. Here a value of 8.1% was recorded for a flow rate of 3.6 m/s. The results of the 18 tests are given in Tables VI and VII. The results are presented graphically for a single test run. Figures 8 and 9 show concentration and exposure as a function of time upstream and downstream of the filter. Figure 10 is a representative plot of fiber length distribution upstream and downstream of the filter and, as can be seen, there was little fiber breakup through these filters.

III. AIR CONDITIONING DUCT TESTS

A. Description of Tests.

The object of the duct tests was to determine the possible breakup of carbon fibers through air conditioning duct work. The test duct consists of two 1-meter lengths of 15 cm diameter duct joined by a standard 90 degree elbow. A blower connected to one end draws air through the duct at a velocity that was measured and held at 6 m/s. Six cylindrical sticky tape detectors were mounted within the duct, three before and three after the elbow, arranged as shown in Figure 11. The tests were performed in the ECOM chamber with Hercules AS fibers in two nominal lengths, 7 mm and 13 mm. The duct-blower assembly ingests chamber air and exhausts back into the chamber. Fibers were introduced into the chamber and the concentration was held relatively constant until the exposure in the chamber became approximately 1 x 10^6 fiber-seconds/m^3. After the test run, the sticky cylinders were cut, mounted flat in 35 mm slide holders, and projected magnified 10 times onto a screen where the fibers were counted and measured for length. Fiber breakup was assessed by comparing the mean fiber length before and after the elbow.

B. Results.

The results are presented in Table VIII. The six runs show that the mean fiber length was the same before and after the elbow indicating that the fibers traverse the elbow without breaking.

IV. GENERIC CABINET TESTS

A. Description of the Tests.

The cabinet in which a piece of electronic equipment is housed may affect the exposure of the enclosed electronics to carbon fibers.

TABLE VI FILTER TRANSMISSION RESULTS

FILTER: ROOM AIR CONDITIONER (FIBERGLASS, 12 mm thick)

RUN NO.	FIBER LENGTH (mm)	AIR VEL (m/s)	FIBER TRANSMISSION (%) INPUT EXPOSURE X 10^{-5} fiber-s/m^3						DISCRIM CUTOFF (mm)	Δ P (mm of water)
			1	5	10	20	50	100		
1	3.5	0.5	*	0.4	0.4	5.2	2.8	2.0	2.0	0.1
2	3.5	2.0	*	1.4	1.6	2.6	2.4	3.0	2.0	0.4
3	3.5	3.6	3.0	5.4	5.9	7.1	6.9	8.1	2.0	0.4
4	7.5	0.5	7.0	1.4	0.7	0.4	0.1	0.1	3.5	0
5	7.5	2.0	*	0.2	0.3	0.7	1.3	1.6	3.5	0.6
6	7.5	3.6	*	2.0	1.8	1.8	1.5	1.6	3.5	1.3
7	15	0.5	*	*	*	*	*	*	4.0	0
8	15	2.0	*	*	*	0.1	0.4	0.3	4.0	0
9	15	3.6	1.0	3.0	2.8	3.9	4.2	4.1	4.0	0

FIBER - HERCULES TYPE AS

* LESS THAN 0.1% TRANSMISSION

TABLE VII FILTER TRANSMISSION RESULTS

FILTER: ROOM AIR CONDITIONER (FIBERGLASS, 10 mm thick)

RUN NO.	FIBER LENGTH (mm)	AIR VEL (m/s)	FIBER TRANSMISSION (%) INPUT EXPOSURE X 10^{-5} fiber-s/m^3 1	5	10	20	50	100	DISCRIM CUTOFF (mm)	Δ P (mm of water)
1	3.5	0.5	2.0	0.4	0.2	0.1	0.1	0.1	2.0	0.1
2	3.5	2.0	*	1.6	1.9	1.5	1.0	1.1	2.0	0.4
3	3.5	3.6	5.0	2.8	2.5	2.7	3.2	3.6	2.0	1.3
4	7.5	0.5	*	*	*	*	0.2	0.1	3.5	0
5	7.5	2.0	*	0.6	0.3	0.2	0.2	0.2	3.5	0.3
6	7.5	3.6	*	0.4	1.0	0.9	1.0	1.1	3.5	1.0
7	15	0.5	*	0.4	0.2	0.1	0.1	*	4.0	0
8	15	2.0	*	*	*	*	0.2	0.2	4.0	0
9	15	3.6	1.0	0.3	0.3	0.3	1.9	3.6	4.0	1.0

FIBER - HERCULES TYPE AS

* LESS THAN 0.1% TRANSMISSION

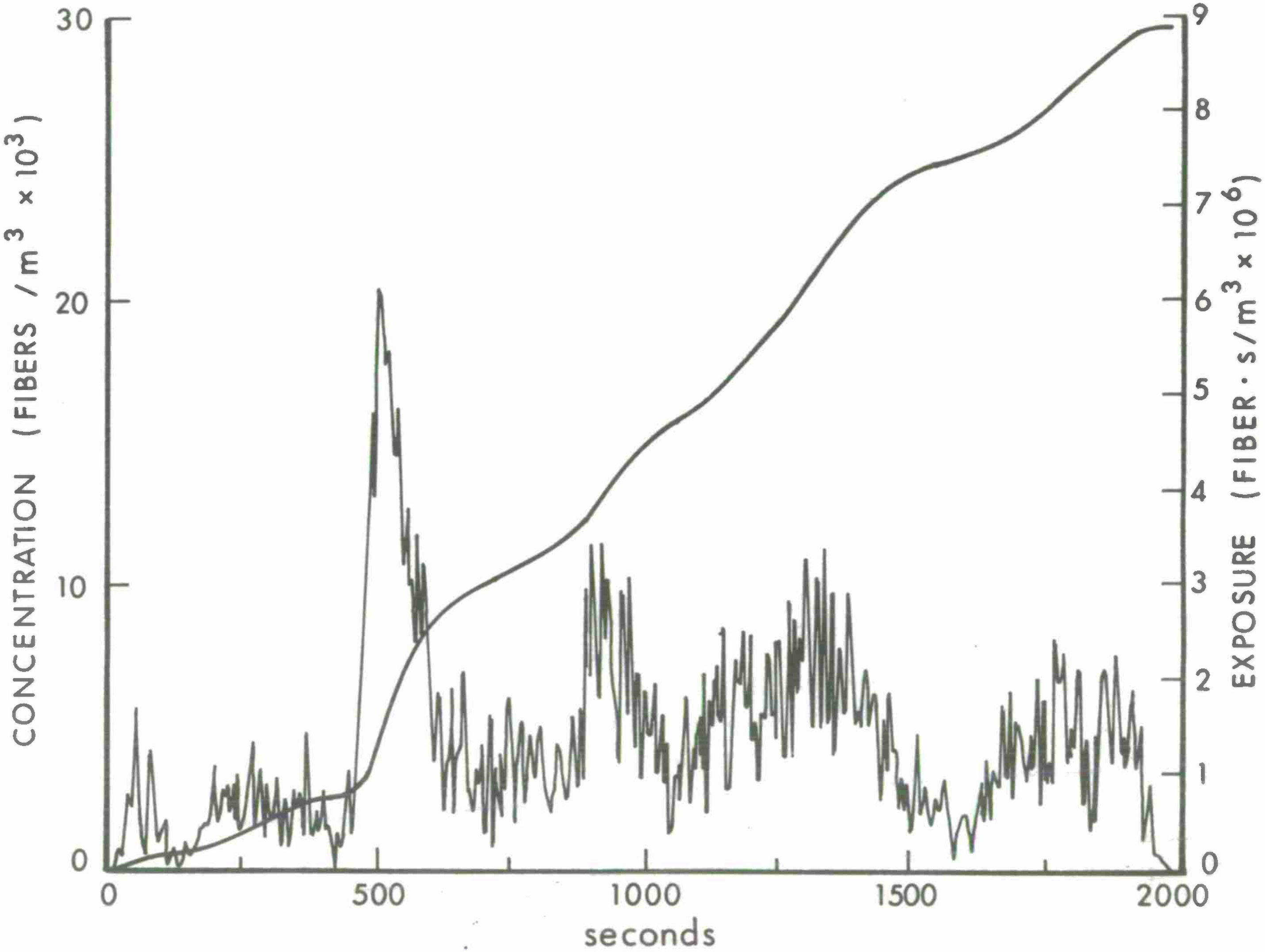

Figure 8. Typical Upstream Concentration and Exposure Plot for Air Conditioner Filter

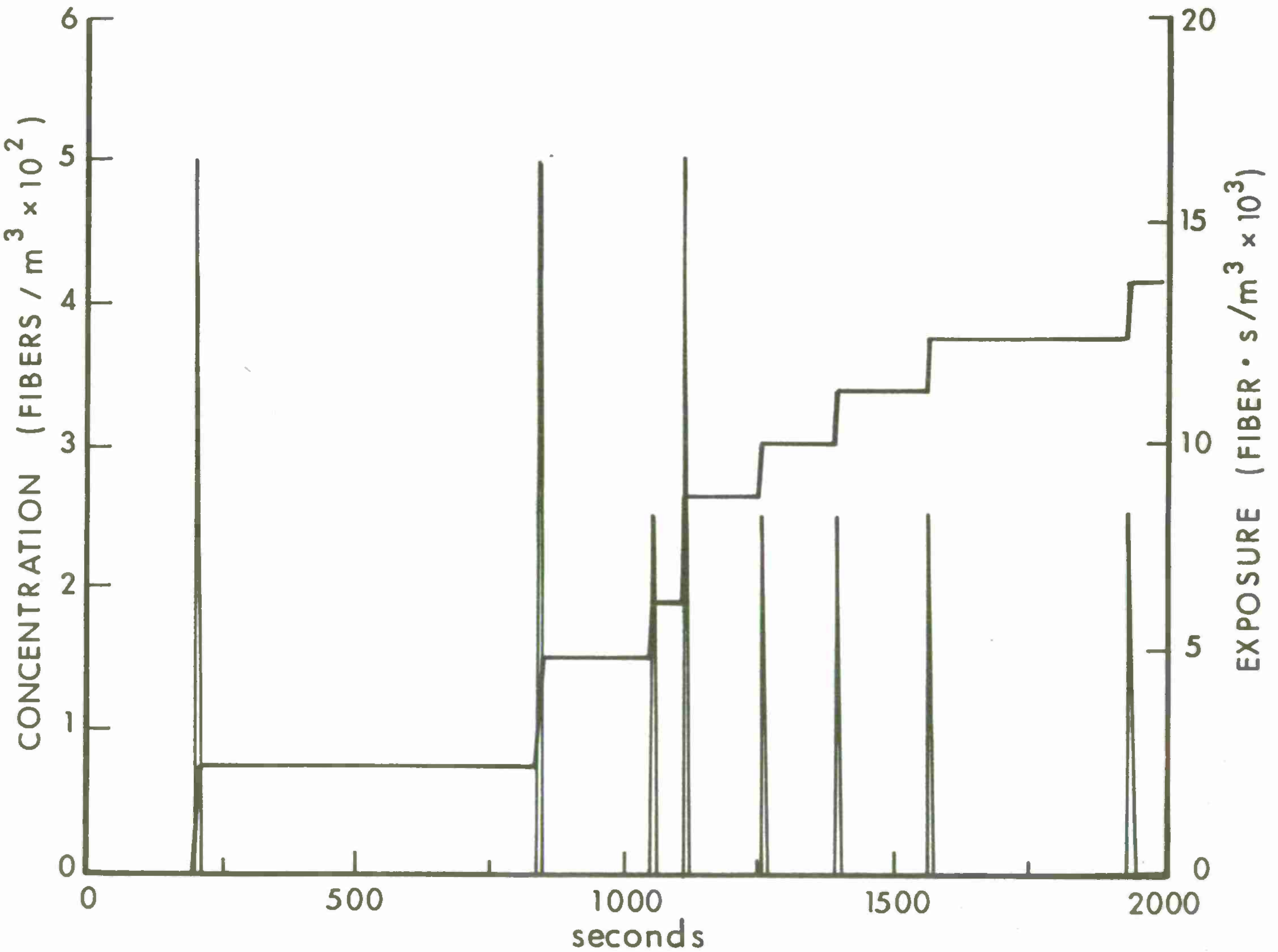

Figure 9. Typical Downstream Concentration and Exposure Plot for Air Conditioner Filter Tests

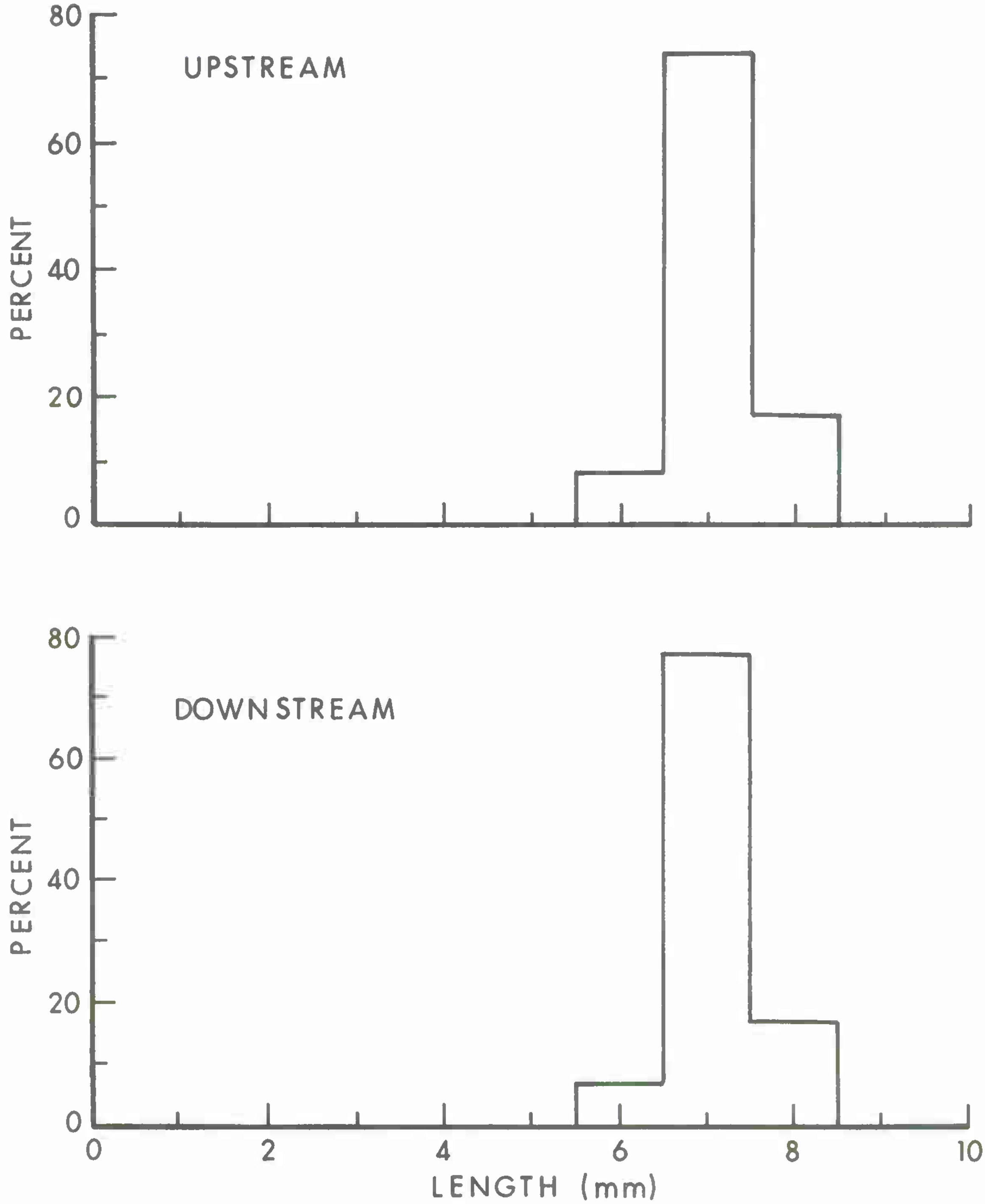

Figure 10. Typical Length Distributions for Air Conditioner Filter Tests

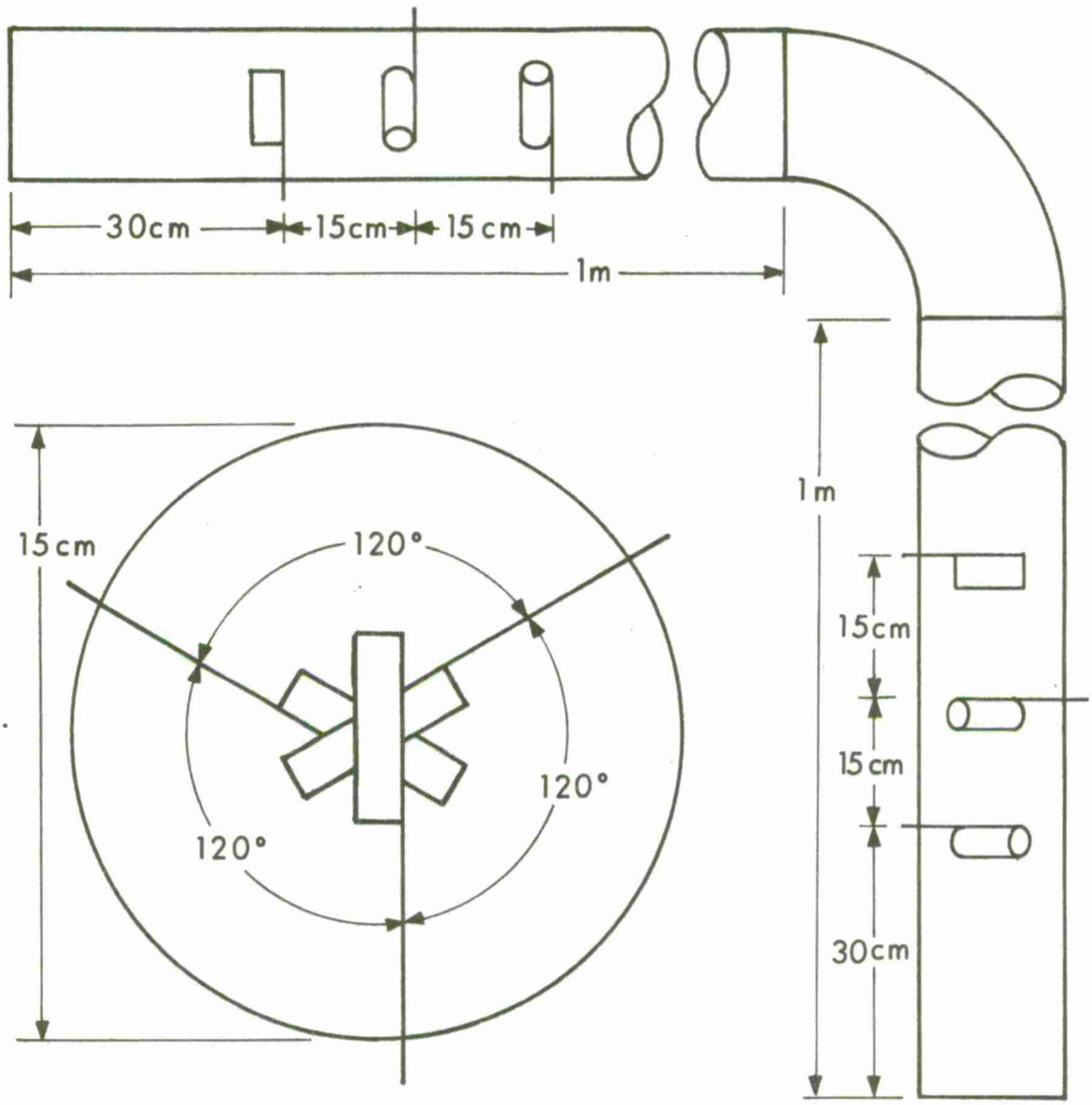

Figure 11. Experimental Apparatus for Fiber Breakup Tests

TABLE VIII. DUCT TESTS LENGTH DATA SUMMARY

RUN No.	MEAN FIBER LENGTH (mm) BEFORE ELBOW	AFTER ELBOW
1	7.0	7.0
2	6.7	7.1
3	6.9	6.9
4	12.5	12.0
5	14.0	13.5
6	12.1	12.5

AIR VELOCITY - 6m/s

FIBER -HERCULES TYPE AS

The generic cabinet tests were designed to give numbers for the transfer of carbon fibers from the outside to the inside of the cabinet (the transfer function) for both convective and fan-forced air flow. The dimensions of the cabinet were typical of large rack mounted or counter-top electronic equipment 48 cm x 48 cm at the base and 33 cm high. Feet on the bottom of the cabinet raised the cabinet 2.5 cm above the table on which it was tested. All panels, top, bottom, and side, were replaceable so that tests for both convective air flow and fan-forced air flow could be made with the same cabinet. No air filters were used.

For the convective air flow tests, the top and bottom panels were perforated with either slots or holes and the open areas top and bottom were made the same. This was 90 cm^2 for the holes and 400 cm^2 for the slots. The holes were 6.4 mm in diameter; the slots were 3.2 mm wide. The interior of the cabinet was heated by two electrical heating elements, each of which has a surface area of 300 cm^2. The heat input, in watts, is given for each test in Tables IX and X.

For the fan-forced air flow tests, an 11.4 cm diameter muffin fan delivering 0.05 m^3/s and blowing into the cabinet was used; the heater was not used. Tests were made with the fan in two locations, 1) at the center of the bottom panel and 2) on one side near the bottom and centered on the side. Two of the side panels had slotted openings 3.2 mm wide in the upper one-third of the panel providing 219 cm^2 open area for the leaving air.

The cabinet tests were made in the ECOM chamber. Fibers were introduced into the chamber until the exposure outside the cabinet became about 1×10^7 fiber-seconds/m^3. This was determined with two charge transfer ball detectors mounted at opposite ends of the table that supported the cabinet. The height of the table was such that the cabinet and the ball detectors were positioned halfway between the ceiling and floor of the chamber. A third ball detector inside the cabinet determined the inside exposure, and the ratio of the inside to the outside exposure is the transfer function. Deposition was determined with 39 mm square sticky tapes placed in four locations on the bottom of the cabinet.

B. Results.

The results of the convective air flow cabinet tests are given in Tables IX and X. For the cabinet with the holes, the range of values for the transfer function is from 0.1% to 9%; for the cabinet with the slots the range is from 1% to 14%. The larger values for the cabinet with the slots is consistent with the 4.4 times greater open area of the slots. For the cabinet with the holes the transfer function decreases markedly with an increase in the rate of heating, indicating that the heated air exits the holes with sufficient velocity to reduce the entry of falling fibers.

TABLE IX

TRANSFER FUNCTION - GENERIC CABINET

CONVECTIVE AIR FLOW

HOLES IN TOP AND BOTTOM PANELS

RUN NO.	FIBER LENGTH (mm)	HEATER (WATTS)	EXPOSURE x 10^{-5} fiber-s/m^3		TRANSFER FUNCTION (%)	DEPOSITION X 10^{-3} f/m^2
			OUTSIDE	INSIDE		
1	3.5	0	180	16.0	9.0	45
2	3.5	0	190	14.0	7.4	34
3	3.5	100	200	1.2	6.0	28
4	3.5	100	150	1.9	1.3	55
5	3.5	250	270	1.4	0.5	84
6	3.5	250	180	2.0	1.1	65
7	7.5	0	120	3.1	2.6	20
8	7.5	0	140	4.7	3.4	35
9	7.5	100	140	0.2	0.1	16
10	7.5	100	130	3.9	3.0	19
11	7.5	250	130	0.2	0.3	15
12	7.5	250	130	0.3	0.3	10
13	10	0	60	0.5	0.8	14
14	10	100	88	0.3	0.4	16
15	10	250	50	0.1	0.2	9

FIBER - HERCULES TYPE HMS

TABLE X

TRANSFER FUNCTION - GENERIC CABINET

CONVECTIVE AIR FLOW

SLOTS IN TOP AND BOTTOM PANELS

RUN NO.	FIBER LENGTH (mm)	HEATER (WATTS)	EXPOSURE x 10^{-5} fiber-s/m^3 OUTSIDE	INSIDE	TRANSFER FUNCTION (%)	DEPOSITION X 10^{-3} f/m^2
1	3.5	0	220	24.0	11.0	88
2	3.5	0	190	20.0	11.0	88
3	3.5	100	190	16.0	9.0	84
4	3.5	100	230	25.0	11.0	85
5	3.5	250	190	26.0	14.0	78
6	3.5	250	190	22.0	12.0	72
7	7.5	0	170	9.0	5.0	24
8	7.5	0	140	7.4	5.0	30
9	7.5	100	240	9.0	4.0	21
10	7.5	100	190	7.3	4.0	31
11	7.5	250	110	7.8	6.9	33
12	7.5	250	190	9.9	5.2	30
13	10	0	110	2.1	2.0	74
14	10	100	110	2.2	2.0	35
15	10	250	110	1.4	1.0	15

FIBER - HERCULES TYPE HMS

The results for the fan-forced air flow cabinet tests are given in Table XI. With fan-forced air flow the transfer function was virtually 100%.

V. SUMMARY

Air filters, even coarse ones such as window screen, greatly reduce the transmission of carbon fibers. In general, the transmission of fibers through an air filter increases with increasing air flow rate and with decreasing fiber length; it decreases with increasing exposure. The screen transmitted only a few percent of the incident fibers when the air flow rate was 0.5 m/s, and was almost as effective at higher air flow rates when the fibers were 7.5 mm or longer. But at 3.6 m/s, the transmission of the 3.5 mm fibers was 16% at the final exposure level (1×10^7 fiber-s/m^3), and was much higher at lower levels of exposure. The 25 mm thick fiberglass furnace filters were effective at the 3.6 m/s air flow rate; the transmission of fibers through the new filters was generally less than 3%, and much less for lower rates of air flow. Fiber transmission was generally higher through the filters that were used before testing. The 10 mm and the 12 mm thick fiberglass filters were nearly as effective as the furnace filters. The transmission of fibers through the pleated panel filters was very low, less than 0.1%, even at the highest flow rate. None of the filters tested caused breaking of the fibers.

The air conditioning duct tests showed that carbon fibers will traverse a 90 degree elbow turn at 6 m/s without breaking. The generic cabinet tests showed that with fan forced cooling, and no air filter, the carbon fiber exposure inside the cabinet will be the same as outside. However, with convective air flow, the inside exposure will be much less; it ranged from a fraction of a percent to 14% for these experiments.

TABLE XI

TRANSFER FUNCTION - GENERIC CABINET

FAN FORCED AIRFLOW

RUN NO.	FIBER LENGTH (mm)	FAN LOCATION	EXPOSURE x 10^{-5} fiber-s/m^3 OUTSIDE	INSIDE	TRANSFER FUNCTION (%)	DEPOSITION X 10^{-5} f/m^2
1	3.5	SIDE	130	94	72	3.0
2	3.5	SIDE	130	108	83	3.4
3	3.5	BOTTOM	130	143	110	4.8
4	3.5	BOTTOM	130	123	95	4.6
5	7.5	SIDE	120	104	87	3.7
6	7.5	SIDE	110	94	85	3.8
7	7.5	BOTTOM	120	122	102	4.5
8	7.5	BOTTOM	120	118	98	4.6
9	10	SIDE	120	102	85	3.9
10	10	BOTTOM	120	106	88	4.0

FIBER - HERCULES TYPE HMS

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